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Study and Analysis of Leaking Underground Storage Tank Remediation Techniques Incorporated in States in EPA Region 6

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A Study and Analysis of Leaking Underground Storage Tank Remediation Techniques Used in EPA Region 6

An Environmental Research Project Submitted to the Underground Storage Tank Section of EPA Region 6 as a Reference to Underground Storage Remediation

By

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Dallas, Texas

March, 1990

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The intent of this research project was initially to determine the effectiveness of groundwater remediation techniques utilized within EPA Region VI for the cleanup of leaking underground storage tanks. This paper concluded that effectiveness of groundwater remediation is primarily dependent on the choice of remediation parameters rather than the type of technique used. Furthermore, the choice of remediation parameters depends on the value of hydrogeologic parameters that characterize the site and are determined during the initial site assessment.

Underground storage tanks, Environment, Remediation, Groundwater

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INTRODUCTION

In early June, 1989, Ed Kennedy was contacted by Dr. Gerald Nehman, Director of the Environmental Institute of Technology Transfer at the University of Texas at Arlington, concerning submitting a National Network for Environmental Management Studies (NNEMS) research Proposal. The purpose of the research was to determine "the effectiveness of surface and ground-water remediation techniques being utilized by states in EPA Region 6, with Leaking Underground Storage Tanks (LUST) Trust Fund leaking tank response programs in place (Research Question 2305)." This question had been posed by Mr. Lynn Dail, Region 6 UST Project Officer.

A research proposal (see NNEMS Project Proposal, Appendix A), subsequently submitted by Ed Kennedy to the Underground Storage Tank (UST) Section of EPA Region 6, was approved by that section.

A primary objective of this project was to gather information on LUST remediation activity throughout Region 6, make this information available to the states and ultimately make recommendations concerning the most effective remediation techniques as determined by an analysis of the data.

LUST REGULATORY BACKGROUND

As outlined in the proposal, much of this LUST research project involved creation of a database with the appropriate parameters that define each remediation site. Since the research proposal targeted LUST Trust Fund projects which form a well defined subset of the UST universe, only Trust Fund remediated site data was collected.

Subtitle I of the Solid Waste Disposal Act (SWDA) as Amended by the Hazardous and Solid Waste Amendments(1984) Sec. 9001 and subsequent federal regulations define an Underground Storage Tank (UST) as "any one or combination of tanks (including underground pipes connected thereto) that is used to contain an accumulation of regulated substances, and the volume of which (including the volume of underground pipes connected thereto) is 10 percent or more beneath the surface of the ground." In 1986, the Resource Conservation and Recovery Act (RCRA, the 1976 amendment to the Solid Waste Disposal Act) was amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) to provide funds to clean up petroleum releases from USTs. A motor fuel tax of $.001 per gallon provides the funding for the LUST Trust Fund which makes money available to states for LUST cleanups involving petroleum releases. According to the Federal Register (FR, Vol.53, No.185) Rules and Regulations (37116), petroleum, as defined under CERCLA, sections 101(14) and 101(33) includes "crude oil and refined fractions of petroleum including gasoline and diesel fuels. The term 'petroleum' includes the inherent 'hazardous substance' constituents in crude or refined oil but does not include contaminants present in or mixed with the petroleum".

The primary chemical groups in petroleum include the Paraffins (e.g., methane), the Napthenes, Olefins, Aromatics (e.g., benzene) and inorganics. Additionally, gasoline additives are inherent "hazardous substances" and include metal-organic compounds, phosphates, halogenated compounds, amines, alcohols, phenols and acids.

All of these groups pose a serious threat to surface and groundwater quality and subsequently to the environment and public health in the event of a release.

The research question focuses on the effectiveness of surface and ground-water remediation techniques used at LUST sites. The publication, Underground Storage Tank Corrective Action Technologies, (1986) defines effectiveness as "how well corrective action (remediation) technology accomplishes its intended purpose such as containment, diversion, removal, destruction or treatment". Surface water includes surface lakes and streams while ground water pertains to both confined and unconfined aquifers. This study concentrates primarily on ground-water remediation. Subpart F (Release Response and Corrective Action for UST Systems Containing Petroleum or Hazardous Substances) of Title 40 C.F.R. Part 280, Sec. 280.66, requires that some corrective action (i.e., remediation) be taken after confirmation of a release and an initial site characterization has been completed. According to Paragraph b, Sec. 280.66, a corrective action plan (CAP) for site remediation should consider: (1) The physical and chemical characteristics of the regulated substance, including its toxicity, persistence and potential for migration; (2) Hydrogeologic characteristics of the facility and surrounding area; (3) Proximity, quality and current and future uses of nearby surface and ground water; (4) The potential effects of residual contamination on nearby surface water and ground water; (5) An exposure assessment and; (6) Any information assembled in compliance with this Subpart.

Since one objective of the research proposal was to create a database, and given the above regulation for a CAP and the focus of this study on contaminant transport in the saturated zone, some basic database parameters were initially defined. Six general categories of database parameters or characteristics used for this study were: 1) Location of site, 2) Location of remediation contractor, 3) UST characteristics, 4) Leakage characteristics, 5) Hydrogeologic characteristics and 6) Remediation characteristics.

CREATION OF LUST DATABASE

The purpose of the database was to serve as the basis from which to do any quantitative or qualitative analysis that might help define or measure the "effectiveness" of ground-water remediation techniques. Another intent of the database is to enable interested parties to review the methods of remediation used within EPA Region 6. Since information about the company responsible for remediation is given, that company may be contacted for further information if an agency or individual so desires. All the parameters listed in Table 1 were initially intended to aid in characterizing each site. For the database, each parameter defines a field and each site comprises a record. The units for numeric values appear next to each parameter. For purposes of consistency and comparison, all values for volume, area and distance are given in English units while concentrations of hydrocarbon components are given in parts per billion (ppb) unless otherwise specified in which case concentrations would be mg/l or ppm. For more information about the database and how to access it, refer to Appendix B.

In order to create the database, the various UST State Programs within Region 6 were contacted. An initial visit was made to the Texas Water Commission (TWC) to review their remediated site files followed by a visit to the New Mexico Environmental Improvement Division. Although the files at both agencies contained large amounts of case information, especially concerning enforcement activity, many files had little or no information on leakage while data on hydrogeologic and remediation characteristics was incomplete.

Although a CAP does not explicitly require leakage characteristics, knowledge of those leakage characteristics noted in Table 1 can be extremely useful in defining a CAP. Certainly knowing the rate of leakage and duration will yield the total volume of leaked product. However, it must be acknowledged, this information may

Table 1

LUST Database Study Parameters (DATA BASE NAME)

Location of site:

1. Name of remediated facility (NAME)
2. Address (ADDRESS)
3. State (STATE)
4. Zip (ZIP)
5. LUST I.D. (LUSTID)
6. Date of notification (DATNOT)
7. Priority (PRIOR)

Location of contractors:

8. Name (NAME1)
9. Address (ADDRESS1)
10. State (STATE1)
11. Zip (ZIP1)
12. Telephone (PHONE1)

UST characteristics:

13. Total tank volume (TVOL in gallons)
14. No. of tanks (NUMTK)
15. Tank construction (TKCONS)
16. Tank age(s) (TKAGE in years)

Leakage characteristics:

17. Type of product (TYPROD)
18. Contaminate concentration before remediation - range (CONTCNB in ppb)
19. Contaminate concentration after remediation - range (CONTCNA in ppb)
20. Rate of leakage (RTLEAK in gallons/day)
21. Duration (DURA in days)
22. Areal extent (ARLK in $ft.^2$)
23. Vertical extent (VERLK in ft.)

Hydrogeologic characteristics:

24. Soil type (SOILT)
25. Hydraulic conductivity - horizontal (K in ft./minute)
26. Hydraulic gradient (GRAD)
27. Depth to groundwater (DEPGR in ft.)
28. Transmissivity (TRANSM in ft^2/day)
29. Groundwater Velocity (GWVEL in ft/day)
30. Porosity (POR, $0 < n < 1$)

Remediation parameters:

31. Date remediation began (DATRB)
32. Date remediation completed (DATRC)
33. Plume indicator (PLMIND)
34. Technique (REMTEC)
35. Comments concerning remediation process (COM)

not be easy to determine and in many cases, must rely on accurate records of product inventory which may not be available. The areal and vertical extent of the contaminant plume defines the geometric boundaries of the leakage problem and, at some point, must be accurately approximated.

As this paper will attempt to point out, effective remediation will depend extensively on knowledge of the hydrogeologic parameters, which, as Sec. 280.66 of Title 40 C.F.R. 280 requires, is a necessary condition for an effective CAP. Therefore the States should prioritize collection of the hydrogeologic characteristics (see Table 1) during an initial site assessment since it is these characteristics that must be used in remediation planning.

For this study, it was originally intended to compare remediation techniques in terms of cost, impact on water quality as measured by contaminant concentrations before and after remediation, and containment of the plume. However, since cleanup costs in most cases are incurred by the Responsible Party (RP), cost information was not available in the files reviewed. Contaminant plume containment was difficult to quantify because the plume changes with time and is dependent on the indicator substance used to define the plume.

Finally, there is the use of water quality as a measure of ground-water remediation effectiveness. Although most files had contaminant concentration data on benzene, toluene, ethylbenzene, and xylene (BTEX) before and after remediation, the values varied from one monitoring well to another and within the same monitoring well (MW), from one point in time to another which is to be expected if there is any ground-water flow and/or water table fluctuation. To illustrate this point, reference is made to Table 2 of a Terracon Environmental Well Analysis obtained from the TWC LUST Program files (TWC LUST ID No. 91331). Note the significant

Table 2

TERRACON ENVIRONMENTAL, INC.

Table II
Star Mart #3 Well Analyses
Dallas, Texas
Job No. 50875001

Well	Date	Benzene	Toluene	Xylene	Total BTX
MW-1	Feb 20, 1987	0.02	0.13	0.44	0.59
	Dec 26, 1987	*	*	*	0
	Jul 14, 1988	0.073	0.005	0.006	0.084
	Feb 2, 1989	*	*	*	0
	Apr 27, 1989	*	*	*	0
MW-2	Feb 20, 1987	96.57	148.79	27.2	272.56
	Dec 26, 1987	6.8	17.1	5.5	29.4
	Jul 14, 1988	2.31	2.94	5.31	10.56
	Feb 2, 1989	10.6	17	18	45.6
	Apr 27, 1989	0.18	1.2	3.14	4.52
MW-3	Feb 20, 1987	114.61	252.37	37.36	404.34
	Dec 26, 1987	18.4	23.6	4.85	46.85
	Jul 14, 1988	4.39	6.64	9.44	20.47
	Feb 2, 1989	6.37	3.17	9.3	18.84
	Apr 27, 1989	4.5	4.06	32.53	41.09
MW-4	Feb 20, 1987	0.44	0.13	1.2	1.77
	Dec 26, 1987	0.22	*	*	0.22
	Jul 14, 1988	1.19	0.185	0.103	1.478
	Feb 2, 1989	0.11	*	0.13	0.24
	Apr 27, 1989	1.05	0.02	0.12	1.19
MW-5	Feb 20, 1987	0.06	0.03	1.04	1.13
	Dec 26, 1987	*	*	*	ND
	Jul 14, 1988	*	*	*	ND
	Feb 2, 1989	0.03	*	0.02	0.05
	Apr 27, 1989	*	*	*	ND
MW-7	Feb 20, 1987	16.29	2.8	28.5	47.59
	Jul 14, 1988	9.01	1.85	6.43	17.29
	Feb 2, 1989	17.1	4.27	35.5	56.87
	Apr 27, 1989	1.88	0.22	1.34	3.44
MW-8	Feb 20, 1987	14.3	3.27	7.15	24.72
	Dec 26, 1987	3.05	*	0.43	3.48
	Jul 14, 1988	7.15	0.452	2.25	9.852
	Feb 2, 1989	6.05	0.19	4.88	11.12
	Apr 27, 1989	1.1	0.14	1.15	2.39

Table II (cont.)

Well	Date	Benzene	Toluene	Xylene	Total BTX
MW-9	Feb 20, 1987	2.33	8.14	8.87	19.34
	Dec 26, 1987	2.31	0.77	0.1	3.18
	Jul 14, 1988	0.308	0.14	0.677	1.125
	Feb 2, 1989	0.39	0.08	0.31	0.78
	Apr 27, 1989	0.04	0.02	0.06	0.12
MW-10	Feb 20, 1987	4.51	6.34	25.82	36.67
	Dec 26, 1987	3.06	0.15	0.29	3.5
	Jul 14, 1988	9.2	6.43	11.8	27.43
	Feb 2, 1989	5.3	1.45	6.26	13.01
	Apr 27, 1989	1.48	0.32	1.58	3.38
MW-11	Jul 18, 1987	78.98	94.61	208.12	381.71
	Jul 14, 1988	*	0.007	0.006	0.013
	Feb 2, 1989	1.44	0.33	1.5	3.27
	Apr 27, 1989	1.2	0.5	18.83	20.53
MW-12	Jul 18, 1987	15.46	18.52	23.9	57.88
	Dec 26, 1987	1.1	*	*	1.1
	Jul 14, 1988	0.663	*	*	0.663
	Feb 2, 1989	0.87	0.02	0.12	1.01
	Apr 27, 1989	0.17	0.03	0.1	0.3
MW-13	Jul 18, 1987	23.86	28.58	41.34	93.78
	Dec 26, 1987	8.35	*	*	8.35
	Jul 14, 1988	5.8	0.365	1.69	7.855
	Feb 2, 1989	32.3	1.26	13.9	47.46
	Apr 27, 1989	3.26	1.11	4.1	8.47
MW-14	Jul 18, 1987	6.33	5.47	10.72	22.52
	Dec 26, 1987	2.79	*	0.23	3.02
	Jul 14, 1988	5.97	0.432	1.81	8.212
	Feb 2, 1989	0.75	*	0.08	0.83
	Apr 27, 1989	0.07	*	0.02	0.09
MW-15	Jul 18, 1987	0.89	0.9	*	1.79
	Dec 26, 1987	*	*	*	ND
	Jul 14, 1988	0.128	0.013	0.271	0.412
	Feb 2, 1989	0.02	*	*	0.02
	Apr 27, 1989	0.01	0.16	1.85	2.02
MW-16	Jul 18, 1987	*	*	*	ND
	Dec 26, 1987	*	*	*	ND
	Jul 14, 1988	*	*	*	ND
	Feb 2, 1989	*	*	*	ND
	Apr 27, 1989	*	*	*	ND

Table II (cont.)

Well	Date	Benzene	Toluene	Xylene	Total BTX
MW-17	Mar 8, 1988	1.375	0.46	1.725	3.56
	Jul 14, 1988	0.064	*	*	0.064
	Feb 2, 1989	*	*	*	ND
	Apr 27, 1989	0.19	*	*	0.19
MW-18	Mar 8, 1988	*	*	*	ND
	Jul 14, 1988	*	*	*	ND
	Feb 2, 1989	*	*	*	ND
	Apr 27, 1989	*	*	*	ND
MW-19	Mar 8, 1988	*	*	*	ND
	Jul 14, 1988	*	*	*	ND
	Feb 2, 1989	*	*	*	ND
	Apr 27, 1989	*	*	0.03	0.03

Note: Detection Levels for Benzene, Toluene and Xylene

Feb 20, 1987	0.01
Dec 26, 1987	0.05
Mar 8, 1988	0.005
Jul 14, 1988	0.005
Feb 2, 1989	0.02
Apr 27, 1989	0.01

* = below detection level
ND = below sum of detection levels (3*)

changes in concentration of BTX over area (i.e., between monitor wells at a given time) and the concentration changes with respect to time for a given location (i.e., same monitor well). Also note that remediation did not come on line until February 24, 1988. Therefore, the large initial drop in BTX concentration in MWs 2,3 between February 20, 1987 and December 26, 1987 and MWs 11, 12, 13 between July 18, 1987 and December 26, 1987, was due to factors other than remediation. These factors can be understood by analyzing the migration of contaminants in groundwater utilizing the mass transport model on which the advection - dispersion equation is based. The transport equation used to describe steady, areal (x, y plane) transport (no vertical migration) with dispersion and decay of a substance in flowing groundwater through an homogeneous, isotropic, medium, is given by:

$$\partial C/\partial t = D_L \partial C^2/\partial^2 x + D_T \partial C^2/\partial^2 y - \bar{V} \partial C/\partial x - G$$

where C is the contaminant concentration at some time t, D_L is the component of the dispersion tensor (a set of functions that relates different vector fields such as might involve a change in a coordinate system) in the longitudinal direction (direction of flow), D_T is the component of the dispersion tensor in the transverse direction, $\bar{V}$ is the average solution velocity in the longitudinal direction (advection component), and G is a decay or general loss factor due to adsorption, absorption, biological decay or some other attenuating factor.

From the above equation $C = f(x, y, t)$ if $\partial C/\partial t \neq 0$ (non-steady state flow). Hence, contaminant concentrations vary in time and space. D_L, D_T and $\bar{V}$ are assumed to be constant for an isotropic, homogeneous aquifer. (Note that $\bar{V}$, the solution velocity, $= V_D/n$ where V_D is the Darcy velocity and n is the effective porosity. $V_D = k\ dh/dl$ where dh/dl is the hydraulic gradient and k is hydraulic conductivity, therefore, $\bar{v} = f(dh/dl, k, n)$).

However, in most real world situations, aquifers are neither homogeneous nor isotropic and don't have uniform gradients which implies $\bar{V}$, D_L, D_T and G are changing spatially, thereby introducing additional and ill-defined sources of variation. Additionally, fluctuations in ground-water level occur seasonally due to aquifer depletion and recharge resulting from variations in precipitation. These changes in ground-water level affect adsorption of hydrocarbons by soil and, therefore, concentrations. Thus, since so many variables besides remediation can effect contaminant concentrations, effectiveness of ground-water remediation cannot be determined exclusively by analyzing water quality from a set or group of monitor wells before and after remediation. Once the contaminant plume has been delineated and a seepage velocity and the direction of migration determined, monitor wells can be located down grade, if necessary, and additional water quality values obtained over time. By continuous sampling at new monitor well locations throughout the migrating plume, remediation effectiveness as measured by plume containment can be determined. However, additional monitoring of concentration changes still will not indicate remediation effectiveness unless, perhaps, the concentration changes are recorded over a long period of time and plume containment has occured, i.e., migration has ceased. One possible way to measure remediation effectiveness as a function of contaminant concentration could involve the use of mass balances (see Appendix B for more comment on this idea). For purposes of this study, use of contaminant concentration data is not practical because of the large variations of concentration over time and area independent of remediation. Therefore, the values that appear in the database for contaminant concentration should be used to give the reader an idea of the ranges of concentrations that might appear in a monitor well at various LUST sites but should not be used as a measure of remediation effectiveness.

Since the original plan to analyze remediation effectiveness in terms of cost, plume containment and changes in contaminant concentration had to be abandoned, it was decided to analyze existing remediation techniques in an effort to deduce when and why those techniques work.

SUMMARY OF REMEDIATION TECHNIQUES

In order to better understand the techniques used in surface-water or ground-water remediation, a review of the literature pertaining to existing techniques was conducted. Perhaps the best reference available was the EPA - Office of Underground Storage Tanks (OUST) Publication titled Cleanup of Releases from Petroleum USTs: Selected Technologies. Summarizing, there are two general ground-water remediation situations: 1) the separation or removal of free product from ground water, 2) the removal and treatment of product dissolved in ground water. (Note: the literature does not mention surface-water remediation explicitly and the database contains no specific cases of surface-water cleanup but the same techniques used to separate product from ground water are applicable to surface water.)

Free product recovery utilizes three basic techniques: 1) the trench method, considered the least expensive, is only effective for moderately permeable aquifers with the top of the aquifer being no more than 15 ft. below ground surface; 2) single pump systems which recover both product and water through a single pipeline (This technique is used primarily when recovery rates are less than 500 gallons per hour (gph) and the spill is relatively small); and 3) dual pumping systems which use separate product and water pumps thus reducing the amount of water which must be treated on the surface.

Removing product dissolved in ground water most often requires removing the contaminated water from the aquifer thereby using the same concepts as those used in free product removal, usually pumping, then treating the pumped water to eliminate the dissolved phase component.

In some cases, soil venting can be used to remove the dissolved phase component. Venting can be a passive technique consisting of vents that are open to the atmo-

sphere or an active system that employs vacuum or pressure pumps to accelerate the removal of soil vapors. Since a large majority of LUST releases involve petroleum product which is immiscible, highly volatile and less dense than ground water, most ground-water contamination is confined to the top of the water table (the interface between the saturated and unsaturated zone). According to Henry's Law, the solubility of a gas in a liquid is proportional to the partial pressure of that gas in contact with the liquid. Thus, as the hydrocarbon vapors in the unsaturated zone dissipate, there is a change in the gas-liquid equilibrium that reduces the concentration of contaminant in the water. In some instances, soil venting can cause the accumulation of free product at the saturated-unsaturated zone interface, probably as a result of decreased vapor pressure in the soil above the interface (see memo field of record 7 in database file ETKLST).

This same concept applies to air stripping, the most common method used to remove dissolved product from pumped waters. Another common technique used to remove volatile organics from water is activated carbon adsorption which utilizes granulated activated carbon to adsorb organics.

Free product separation from ground water employs skimmers, filter separators, surface mounted product recovery pumps, and above-ground product/water separators. Most of the above mentioned processes are used in combination, as indicated by the database analysis, to achieve the desired results. For detailed information on the different remediation techniques, refer to the aforementioned EPA-OUST publication.

For an overview of the aforementioned techniques, three additional short database files have been created. See Appendix B for more information on accessing these files and the information they contain.

ANALYSIS OF DATA

A review of the database indicates common use of the aforementioned techniques. Table 3 displays the remediation techniques used for different "product type" i.e. dissolved and/or free phase ground-water contamination. Of the 16 cases reviewed, none employed the trench method. All cases involving free product removal utilized some form of pumping and overall, 13 of 16 sites used pumping in the remediation process. Two remediation systems used soil venting. For a brief description of remediation activity at each site, access the memo field of the record of interest in the database. (See Appendix B for information concerning use of the database.)

Based on a review of the techniques in the literature and the database, it is apparent that the indications of effectiveness of these techniques depend primarily on the selection of remediation parameters, especially when pumping is used, rather than the type of technique. The choice of remediation parameters in turn relies on the values of the hydrogeologic parameters determined during the initial site assessment. These parameters include the hydraulic gradient (dh/dl, the change in aquifer elevation dh with respect to the change in horizontal distance dl) and hydraulic conductivity (k), depth to ground water or potentiometric surface, aquifer thickness, type of aquifer, soil type and aquifer porosity.

To illustrate the importance of these parameters in pumping remediation techniques, equilibrium and nonequilibrium well equations for both confined and unconfined aquifers with 2-dimensional radial flow must be analyzed. For wells in equilibrium, well yield Q (in gpm) for an unconfined aquifer is:

$$Q = k\,(H^2 - h^2)/1055\,(\log(R/r))$$

where k is hydraulic conductivity, H (ft) is static head measured from the bottom of the aquifer, h (ft) is the depth to water in the well when pumping, R (ft) is the radius of the cone of depression, and r (ft) is the radius of the well. (Note: these equations assume English units for all parameters.)

TABLE 3

RECORD #	STATE	REMEDIATION TECHNIQUE	TYPE PRODUCT
1	TX	9 SOIL VENTING WELLS	MTBE/BENZENE
2	TX	7 MANIFOLDING MONITOR WELLS/AIR STRIPPING	BENZENE/TOLUENE/XYLENE
3	TX	BIOLOGICAL TREATMENT USING ACTIVATED SLUDGE	METHANOL/IPA/ACETONE/MEK/BENZENE
4	TX	DUAL PUMP SYSTEM/AIR STRIPPING	TOTAL BTX/FREE PRODUCT
5	TX	SINGLE PUMP WELL WITH FREEWATER RECIRCULATION	DIESEL (50 GAL)
6	TX	DUAL PUMP RECOVERY SYSTEM WITH FLOATING HC SEPARATOR	BTEX/FREE PRODUCT
7	TX	TEFLON BAILER/ SOIL VENTING	BTEX/FREE PRODUCT
8	TX	DUAL PUMPING SYSTEM/ AIR STRIPPING	BTEX
9	NM	12 IN.DIAM.SINGLE RECOVERY WELL/DUAL TANK BUBBLER AERATION	BTX
10	NM	DUAL PUMPING SYSTEM/TANK TRUCKS/API SEPARATOR	B/T/X//DISSOLVED PHASE,FREE PHASE
11	NM	EJECTOR SYSTEM PUMP/SEPARATOR/AIR STRIPPING	B/T/E/X//FREE PRODUCT-.92 FT.
12	NM	SINGLE PUMP RECOVERY WELLS/AIR STRIPPER	BTX
13	NM	SINGLE RECOVERY WELL/AIR STRIPPING	BTEX
14	NM	SERIES OF RECOVERY WELLS/AIR STRIPPERS	BTX/DISSOLVED PHASE
15	NM	VAPOR EXTRACTION SYSTEM	BENZENE
16	NM	2 DUAL PUMP SYSTEM RECOVERY WELLS/AIR STRIPPING/VAPOR EXTRAC	B/T/X/ SOME FREE PRODUCT ACCUM.W/PUMPING

For a confined aquifer:

$$Q = kb\ (H - h)/528\ (\log\ (R/r))$$

where b is the aquifer thickness.

In the nonequilibrium conditions, the objective of aquifer testing is to determine S (dimensionless storage coefficient), and T which is the transmissivity of an aquifer in (gpd/ft. or $ft.^2/d$). These values can be determined by plotting drawdown versus time or drawdown versus distance observations from monitor wells. Since most pump test are performed under nonequilibrium conditions, an immediate determination of aquifer properties can be made instead of having to wait for equilibrium. The parameters S and T are measures of the water yielding capacity of the aquifer and, therefore, must be known in order to determine Q values for recovery wells.

Of the above parameters for both confined and unconfined aquifers, each, except k (hydraulic conductivity), can be measured by drilling and performing a pump test during the initial site assessment. A pump test requires a pumping well and a minimum of one observation well. Hydraulic conductivity, k, can then be calculated from one of the flow equations. Hydraulic conductivity can also be calculated from the results of a slug test. If the thickness (b) of the aquifer and T is known, then k can be calculated from T = kb.

Once the hydrogeologic parameters are known, then the remediation parameters can be determined. For example, when the areal extent of the plume is delineated, a value(s) can be assigned to R and a Q calculated for that R. Radial flow within R, (the cone of depression) to include the contaminated waters, will migrate toward the well to be captured by pumping. If Q is the limiting factor as determined by S and T, then a system of recovery wells must be designed based on calculated values of R. That system of wells should be set up such that the areal boundaries of the

plume lie within the cone of influence of that well system. Since the areal extent of the plume is difficult to determine, knowledge of the seepage velocity can be very useful in predicting plume migration rates. (In a confined aquifer, ground water flows in response to differences in hydrostatic head due to elevation, velocity and pressure heads. In an unconfined aquifer, flow is dependent only on elevation head). If the hydraulic gradient and direction are known, the seepage velocity ($\bar{V}$), can be found because once k is determined and the gradient and porosity (n) are measured in the field, $\bar{V}$ can be calculated from: $\bar{V} = (k/n)(dh/dl)$.

It should be noted that the aforementioned equations for flow in a pumping well are based on certain assumptions that include uniform aquifer character and hydraulic conductivity, an homogeneous and isotropic aquifer, no recharge and radial flow, i.e., the effects of combined flow (regional and radial flow superimposed) are negligible. However, in areas where local and regional ground water velocities are significantly large, the effects of combined flow must be considered when devising a CAP. A firm knowledge of the local geologic framework can aid in determining the location of impervious boundaries, areas of discharge, variations in leaching and the effects of recharge and discharge within the aquifer. The relevance of these factors is site specific. For example, one site may have significant regional flow while another site may have significant recharge or leaching but low regional flow.

Although most LUST leaks may cover a relatively small area, a large volume remediation project might integrate many of these hydrogeologic variables into a local or regional ground-water flow model. Such models could be used to set up remediation systems involving both recovery and injection wells that might be used for containment.

For ambitious remediation projects, such a model, that integrates many of these relevant parameters, is the United States Geological Survey (USGS) Computer Model of Two-Dimensional Solute Transport and Dispersion of Ground Water by L.F. Konikow and J.D. Bredehoeft. This computer model combines the two dimensional ground-water flow equation with the two dimensional solute transport equation to produce a model from which "concentrations of a dissolved chemical species in an aquifer at any specified place and time" can be computed. The model can be applied to both steady state and transient (most LUST discharges are transient) flow situations. In any ground-water remediation project, where and when to locate recovery wells is one of the ultimate goals of a site assessment and absolutely necessary for effective remediation. However, such modeling can be costly and will be only as accurate as the hydrogeologic data input into the model.

CONCLUSION

Summarizing, accurate measurement of the hydrogeologic parameters permits determination of the following remediation characteristics:

1) R value(s) for pumping recovery wells that will result in capture and containment of contaminated ground water throughout the contaminant plume;
2) Pumping rates (Q) which are dependent on aquifer properties such as specific capacity, drawdown and potential yield;
3) Well efficiency (ratio of theoretical drawdown to actual drawdown) which will effect recovery well design and construction factors;
4) Drawdown within the recovery well(s) that may interfere with wells in a producing aquifer. Note: The interference affects may a) determine the number of wells that have to be pumped to capture a given plume, b) determine well spacing, and/or c) allow for recovery well operation without dewatering surrounding wells outside the plume);
5) Proper location and depth of venting wells or trenches; and
6) Depths at which recovery well(s) must be screened.

Proper well location, construction, screening and flow will insure effective remediation by containing, diverting and removing contaminated groundwater. As previously mentioned, these are three factors used to define "effectiveness" of ground-water remediation and must be considered necessary conditions for any successful remediation project. In turn, the type and design of surface remediation activity (e.g., air stripping, skimming, product water separators) will depend on the flow of pumped ground water. These systems can thus be designed for optimum performance.

Regardless of remediation technique, knowledge of the direction and seepage velocity ($\bar{v}$) are absolutely necessary for any type of plume containment. Thus, the

hydraulic gradient, bearing of gradient dip, aquifer porosity and hydraulic conductivity (k), must be known. Of course, for the hydraulic gradient $(dh/dl) < < < 1$ or $k < < < 1$, then $\bar{v}$ approaches zero and therefore, is negligible. Some materials, such as compacted clays or shales, may have hydraulic conductivities as low as $10^{-7} - 10^{-6}$ m/day, thus plume migration will be affected primarily by factors such as dispersion and adsorption which are functions of aquifer material properties. This is apparent from the ground-water transport equation as the advection component $\bar{v}$ approaches zero.

For any CAP utilizing pumping to be effective, a range of k must be calculated from field data usually obtained from a pump or slug test (although k can be determined in a laboratory setting using a borehole coring, field determination is preferable). Aquifer characteristics such as S (storage coefficient) and T (transmissivity), which are indicative of the water yielding capabilities of an aquifer must be used to determine pumping rates (Q). Knowledge of recharge and discharge rates can help determine changes in aquifer yield capabilities. Without accurate information on these very basic hydrogeologic parameters, it is doubtful any recovery system, that uses pumping, can be very successful.

The value of hydrogeologic parameter determination was apparent to the EPA authors who promulgated Title 40 C.F.R. Sec. 280.66, which requires that a CAP be preceded by an initial site characterization and that each CAP should consider the "hydrogeologic characteristics of the facility and surrounding area". As noted in EPA - UST Corrective Action Technologies, "the response to releases from USTs depends on several different factors, largely site specific". Although different technologies may be used to remediate the same site, the effectiveness of each technique will depend largely on the accuracy of the hydrogeologic parameters

measured during an initial site assessment and the subsequent selection of a remediation technique with the appropriate parameters based on hydrogeologic information.

Given even the most simplistic of hydrogeologic settings, complete remediation of a LUST site will be a complex, expensive, time-consuming operation, but that is the price which must be paid to insure restoration of the subsurface environment.

Appendix A

NNEMS RESEARCH/PROJECT PROPOSAL

Submitted by: Ed Kennedy
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214-559-4304

Student: University of Texas at Arlington/Graduate Program Of Interdisciplinary Studies

Major Advisor: Gerald Nehman, Ph.D., Director, Environmental Institute for Technology Transfer/817-272-2300

Geographic Preference: Dallas area

Research Question

What is the effectiveness of surface water and groundwater remediation techniques being utilized by states in EPA Region VI, with Leaking Underground Storage Tanks (LUST) Trust Fund leaking tank response programs in place? Question 2305

Proposed Research Plan/Period

1) Define project parameters for the storage tank (e.g. tank age, type product, volume), remediation activity (e.g. cost, remediation technique, duration, type of monitoring procedures, water quality measurements before and after remediation, remediation problems), leakage (e.g. rate of leakage, duration, areal and vertical extent of leakage) and location information. These parameters would be helpful for this project but may be added to or deleted as recommended by UST program managers or others.

2) Contact Region VI state water agencies by phone and, if necessary, visit those agencies to determine the above listed parameter information for each remediated LUST site.

3) Create a LUST database file using DBase software and an EPA PC. Each remediated site would constitute a record consisting of all available parameters obtained from each state agency.

4) Perform analysis using the database to compare methods of remediation, water quality, cost or other parameters. Statistical tests could then be applied to the data to determine if there is a significant difference between remediation techniques and water quality or other parameters.

Expected End Product

The study should provide a comprehensive, permanent database, qualitative and quantitative analysis of remediation techniques examined and the benefits associated with each technique. A database analysis would determine the frequency of remediation techniques and associated problems.

Relevant Student Background/Information

After receiving my B.S. degree from the University of Texas at El Paso in Geoscience, I worked 5 years for Mobil Oil as an exploration geophysicist. Upon leaving Mobil as a result of a work force reduction, I began attending the Graduate Program of Environmental Science at the University of Texas at Dallas and have subsequently transferred to and been accepted at the University of Texas at Arlington. My main interests and area of concentration within Environmental studies is hydrogeology and hazardous waste.

APPENDIX B

1) The database consists of 4 files called ETKLST, ETKFRP, ETKGAS and ETKDIS. ETKLST contains 16 records with each record comprised of 35 fields. Each of the 16 remediation sites studied constitutes one (1) record of the file. The paper files from which the records were compiled varied considerably in parameter information. Some files contained ranges for parameters while others had single values. An original objective at the onset of this project was to statistically analyze the data using correlation or chi square to measure the degree of "relatedness" or statistically significant differences between remediation technique and various hydrogeologic parameters. However, due to: 1) incomplete data, 2) the relatively small size of the database, 3) the uniqueness of each site, and 4) the lack of parameters with which to measure effectiveness, statistical analysis was abandoned as a method to measure effectiveness of remediation techniques. Additionally, as outlined in the paper, contaminant concentration, which is a necessary cleanup parameter, can be independent of remediation technique.

An alternative method to measure remediation effectiveness could involve a mass balance where contaminant mass into the ground = mass out by remediation + mass loss through absorption + mass loss through volatilization. But this method assumes the initial contaminant mass lost into the ground can be approximated and that contaminant mass loss can be calculated.

It should be noted that the 16 sites studied were presented as being representative of the population of LUST Trust Fund remediation projects. The files for these sites were very large consisting of information, much of which was related to communication between agencies and other involved parties. The file, as it exists, should be used for information only and not to draw inferences concerning remediation effectiveness.

ETKFRP is a 3 record file containing information on free product removal techniques. ETKGAS is a 6 record file containing information on free product and water separation. These techniques are used often in tandem with free product removal methods. The last file, ETKDIS, consists of 9 records for methods to remove dissolved phase hydrocarbons from groundwater.

2) The ETKLST database is intended to give the reader information about what techniques have been used in specific cases. All are unique but share some commonality.

3) To access this information, any personal computer system with a 5 1/4 inch disk drive is required. The system must be able to utilize dBASE III PLUS software.

4) The database itself resides on a 5 1/4 inch double sided, high density floppy disk and is included in the folder jacket of the report.

5) When the Dbase program is called and the floppy is inserted in the disk drive, the database files (the only Dbase files residing on the disk) can be attached. By using the "Assistant" Dbase command at the "dot prompt", a Dbase menu is entered and the desired database file can be called.

6) The memo field of each record contains a brief summary of each project or technique.

7) Of course, use of the databases requires some slight familiarity of the Dbase software. Any questions concerning its use may be directed to Mr. Lynn Dail, a USEPA - UST Program Officer at 214-655-6755.

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